Groundwater shoaling impacts on coastal drainage infrastructure (case study: Imperial Beach)

Y. Sangsefidi[1*], K. Bagheri[2], H. Tavakol-Davani, PhD, PE[3]

[1] *Research Assistant, Urban Water Group, San Diego State University, San Diego, California, USA.*
[2] *Research Assistant, Urban Water Group, San Diego State University, San Diego, California, USA.*
[3] *Director, Urban Water Group, San Diego State University, San Diego, California, USA.*

**Corresponding author email: ysangsefidi@ucsd.edu*

Highlights

- Besides marine inundation, low-lying coastal areas are vulnerable to groundwater inundation, exacerbated by the sea level rise (SLR), which threatens urban infrastructures and communities.
- Under a SLR = 2 m scenario, the majority of the stormdrain system capacity in Imperial Beach will be occupied by the projected groundwater shoaling (vulnerable to compound flooding).

Introduction

Global warming increases both the mass and volume of the ocean primarily through the melting of polar icecaps and the thermal expansion of water (Rahimi et al. 2020). The global mean sea level (GMSL) has increased at a rate of ~18 cm/century during the 20th century. Since the mid 1980's, its rate (~3 mm/year) has been faster than any period over at least the last 2800 years. Scientists expect an exponential growth for GMSL throughout this century and beyond (Hoover et al. 2017). Low-elevation coastal zones (LECZ) with dense populations are at a highest risk of different sources of inundation (i.e., marine, groundwater, and surface flow inundations as shown in Fig. 1). SLR can enhance the marine inundation directly and also worsen the other sources of inundations progressively. Currently, over 20 million people of the globe are permanently exposed to marine inundation [falling below Mean Higher High Water (MHHW)] while more than 200 million people are in the 100-year flood plains (vulnerable to temporary extreme sea levels), which changes to double by 2060 (Nicholls 2010; and Neumann et al. 2015).

Besides marine inundation, it is recently recognized that LECZs can also be vulnerable to groundwater inundation especially after considering the growing SLR. In this case, a coastal plain is locally flooded due to a rise of the groundwater table. The groundwater inundation will be more intense if high tides or rainfall events occur (compound flooding occurrence). The rising groundwater may cause long-term problems to inundated urban infrastructures (like stormdrain systems) and freshwater aquifers (due to saltwater intrusion), which requires new adaptation tools and strategies. This study focuses on Imperial Beach (IB) as a "disadvantaged community" in CA, which is surrounded by water from 3 sides: the Pacific Ocean on the west, San Diego Bay on the north, and Tijuana Estuary on the south (Fig. 2).

Methodology

Table 1 shows the used data sources (all elevations are referenced to NAVD88 unless otherwise noted). The water levels are obtained from the San Diego Bay station (9410170) as the closest one to IB. Table 2 presents the water level at MHHW for different SLR scenarios in 2100.

We obtained the steady-state spatial-variable groundwater level from the published GIS data by Befus et al. (2020) (modelling groundwater table across California coast including IB). Their results are presented for three values of hydraulic conductivity (K = 0.1, 1, and 10 m/day) while the resulting groundwater level increases for lower K values. We compared Befus et al. 's (2020) results with temporal mean values of the observed groundwater level from the USGS website. As shown in Table 2, K = 1 m/day is providing the most accurate prediction for the groundwater level in IB ($R^2 > 0.94$ and average error < 30%) while K = 0.1 m/day corresponds to the worst-case scenario for the groundwater emergence and shoaling.

The elevation of upstream and downstream edges of stormdrain lines are stored in the available layer. However, a significant part of the data has unknown values, which was removed from our analysis.

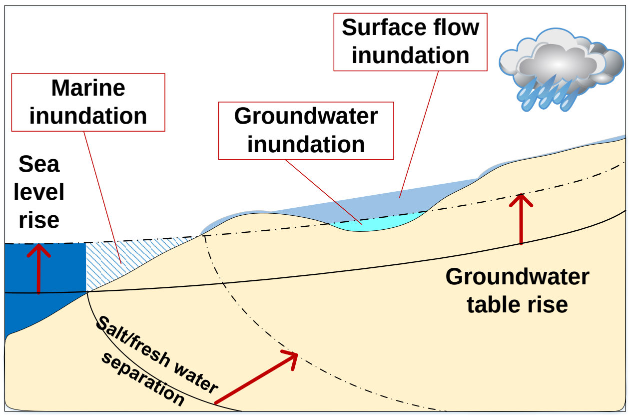

Fig. 1. Different sources of inundation

Fig. 2. IB surrounded by water bodies

Table 1. Description of data sources used in this study

Data		Source	Description
Digital Elevation Model (DEM)		SANDAG ArcGIS Server	Resolution: 2.5 ft × 2.5 ft
Water/tide level		NOAA–Tides and Currents	See Table 2 for 19-year MHHW and SLR scenarios
Groundwater level	Observed data point	USGS–National Water Information System	No active groundwater site in IB (used adjacent sites) High temporal variations (used mean values)
	Modelled spatial data	Befus et al. (2020)–MODFLOW models	Resolution: 10 m × 10 m *K* = 0.1, 1, 10 m/day (Hydraulic Conductivity) Tidal datums = MHHW and LMSL SLR scenarios = 0-5 m
Elevation of stormdrain lines		City of Imperial Beach	Having some missing data

Table 2. Studied scenarios in the present study

Scenario no.	SLR (m)	Water level at MHHW (m)	*K* (m/day)
1	0 (present condition)	1.658	
2	1 (moderate SLR)	2.658	1 (most accurate)
3	2 (high SLR)	3.658	
4	0 (present condition)	1.658	
5	1 (moderate SLR)	2.658	0.1 (worst case)
6	2 (high SLR)	3.658	

Results and discussion

Fig. 3 shows the marine-tidal inundation at MHHW, which clearly enlarges with SLR. Fig. 4 (obtained through a comparison between the elevations of the stormdrain system and groundwater) classifies the stormdrain lines into three different types. As sea level rises, more lines will be inundated by groundwater. Due to its unique situation, IB is vulnerable to SLR, through which a significant part of the stormdrain system capacity may be occupied by subsequent groundwater rise. This will

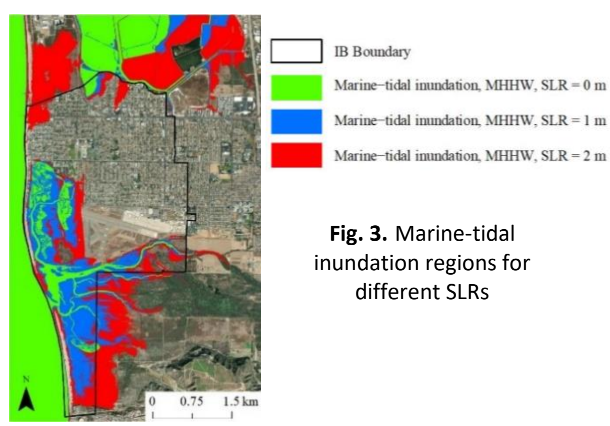

Fig. 3. Marine-tidal inundation regions for different SLRs

make the city vulnerable to compound flooding, i.e. when precipitation coincides with occupied stormdrain systems.

Fig. 4. Stormdrain analysis results

Conclusions

The majority of the IB's stormdrain system capacity could be occupied by SLR-driven groundwater rise. The groundwater intrusion to such an aged system makes it vulnerable to compound flooding, e.g. the coincidence of rainfall events with the occupied system. A comprehensive numerical model will be presented at 12th Urban Drainage Modelling Conference illustrating the vulnerabilities caused by the compound impacts. The model evaluates the drainage system's response to rainfall events and its possible interaction with SLR-driven groundwater rise.

Acknowledgments

This research is supported by U.S. National Science Foundation via grants CBET-2113987 & 2113984.

References

Befus K. M., Barnard P. L., Hoover D. J., Finzi Hart J. A., and Voss C. I. (2020). Increasing threat of coastal groundwater hazards from sea-level rise in California. Nature Climate Change, 10(10), 946-952.

Hoover D. J., Odigie K. O., Swarzenski P. W., and Barnard P. (2017). Sea-level rise and coastal groundwater inundation and shoaling at select sites in California, USA. Journal of Hydrology: Regional Studies, 11, 234-249.

Neumann B., Vafeidis A. T., Zimmermann J., and Nicholls R. J. (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLOS ONE, 10(3), e0118571.

Nicholls R. J. (2010). Impacts of and responses to sea-level rise. Pp. 17–51 in Understanding Sea-Level Rise and Variability. J.A. Church, P.L. Woodworth, T. Aarup, and W.W. Wilson, eds, Wiley-Blackwell.

Rahimi R., Tavakol-Davani H., Graves C., Gomez A., and Fazel Valipour M. (2020) Compound Inundation Impacts of Coastal Climate Change: Sea-Level Rise, Groundwater Rise, and Coastal Precipitation. Water, 12(10):2776.